PHYS 3360 / AEP 3630

Lecture 39

Electrical Noise

- any unwanted electrical disturbance
- either random or periodic / deterministic

Signal to noise ratio

→ magn. of the noise alone is not important

$$SNR_{dB} = 10 \underbrace{\log_{10}}^{\text{common logarithm}} \frac{P_S}{P_N}$$

$$= 20 \log_{10} \frac{V_s}{V_n}$$

Noise figure (e.g. of an amplifier)

$$NF_{dB} = 20 \log_{10} \left[\frac{(V_s/V_n)_{in}}{(V_s/V_n)_{out}} \right] = SNR_{dB}^{in} - SNR_{dB}^{out}$$

> 0 dB always

- characterizes how much addl. noise is introduced
- 0 > 0 dB always, best of low-noise amps have ~0.6 dB

E.g. 1 dB noise figure : degrades S/N by $10^{\frac{1}{20}} \simeq 1.12$ or 12%

~10 dB typical for cheap amps : S/N degrades by ~3

Sources of Noise

I. Intrinsic (internal, due to components)

II. Interference (external or cross-talk, etc.)

Intrinsic sources of noise

1) Johnson (thermal) noise

fluctuations in # electrons in the 2 halves of any conductor

k_B - Boltzmann's const ($= 1.38 \times 10^{-23}$ J/K)

T - temp in Kelvin

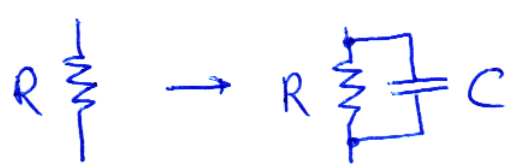
R - resistance in Ω

B - measurement bandwidth in Hz (e.g. circuit response)

$$(v_n)_{rms} = \sqrt{4 k_B T R B}$$

Q: how to see this result?

E.g. consider



Equipatition theorem (stat. mech): a physical system in equilibrium @ temp T has avg. energy $\frac{1}{2}kT$ / degree of freedom

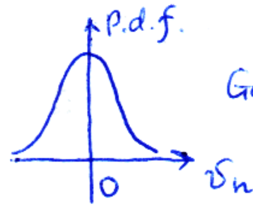
One degree of freedom V: $\langle \frac{1}{2} C V^2 \rangle = \frac{1}{2} kT$, $\langle V^2 \rangle = \frac{k_B T}{C}$

Bandwidth DC to $\omega_c = (RC)^{-1}$: $B \sim \frac{\omega_c}{2\pi} = \frac{1}{2\pi RC}$, =>

$$\langle V^2 \rangle = \underbrace{2\pi}_{\text{slightly off}} k_B R B$$

- "white noise" : noise power / unit BW indep. of freq
  (up to ~10 THz, freq of thermal vibrations)

- "gaussian noise" :



Gaussian

Ex: $R = 20k\Omega$ @ $T = 300K$, $B = 20kHz$ (audio range if age < 50_y)

$\Rightarrow (v_n)_{rms} \sim 2.5 \mu V$

2) Shot noise

discrete electron charge → statistical fluctuations in current
(rain o a tin roof)

$(i_n)_{rms} \sim \sqrt{\frac{N_{carriers}}{sec}}$; $(i_n)_{rms} = \sqrt{2e \underbrace{i_s}_{\text{DC current}} B}$

$\frac{(i_n)_{rms}}{i_s} \propto \frac{1}{\sqrt{i_s}}$

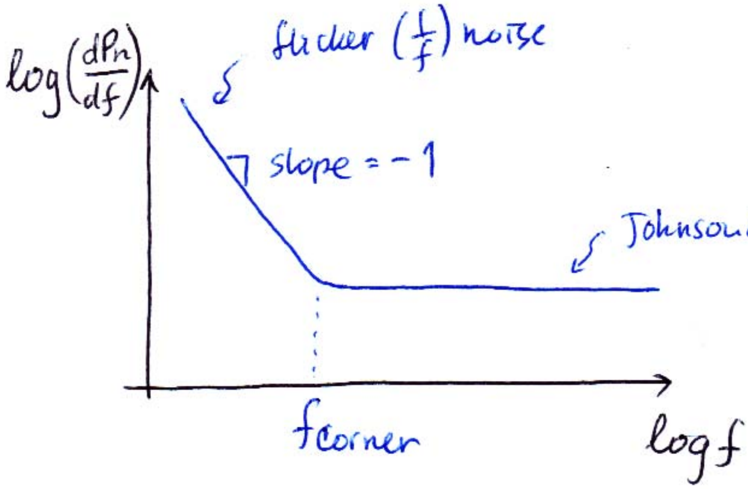
Ex: $i_s = 1A$, $B = 20kHz$, $\Rightarrow (i_n)_{rms} \sim 80nA$, $SNR_{dB} \sim 140dB$

$i_s = 10pA$, —"—, $\frac{(i_n)_{rms}}{i_s} = 2.5\%$ or $SNR_{dB} \sim 30dB$

- also "white" and "gaussian"

3) 1/f (flicker) noise

- many generating mechanisms (e.g. carrier density fluct.)
- $\frac{dP(f)}{df} \propto \frac{1}{f}$ (actually f^{-n} with $n = 0.7 - 1.2$)



f_{corner}: 10kHz – Si diode

1kHz – Schottky d.

~100Hz – resistors

- dominant intrinsic noise source below f_{corner} (~kHz)
- "pink" noise (freq. dep: const → white, $\frac{1}{f}$ → pink, $\frac{1}{f^2}$ → red, ..)
- a.k.a. "excess noise" for resistors
- ↑ when material purity ↓

  e.g. wire-wound resistors have lower flicker noise than carbon-composition

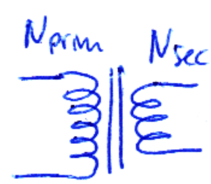
To minimize intrinsic noise

- use low noise components (if flicker n.)
  - metal film vs carbon resistors
  - FETs instead of BJT's
  - lower resistance if dominated by Johnson
- match signal source impedance to amp. charact.

  if v_n, i_n are noise levels for amp, choose

  $R_s = \frac{v_n}{i_n}$ for best SNR at the output

  can use impedance transformers $= \left(\frac{N_{sec}}{N_{prim}}\right)^2$



Q: – limit bandwidth

- operate at lower T